

NO-A183 748

IS VISUAL IMAGERY REALLY VISUAL? OVERLOOKED EVIDENCE
FROM NEUROPSYCHOLOGY(U) CARNEGIE-MELLON UNIV PITTSBURGH
PA DEPT OF PSYCHOLOGY H J FARAH 87 AUG 87 TR-87-14-ONR
N00014-86-K-0094

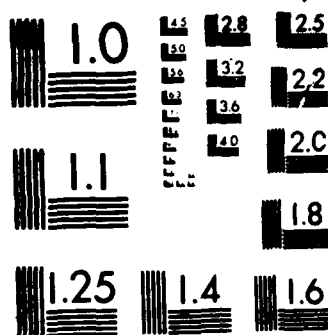
1/1

UNCLASSIFIED

F/G 6/4

NL

END
9-87
DTIC



MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS 1963-A

AD-A183 740

DTIC FILE COPY

16

Is visual imagery really visual?
Overlooked evidence from neuropsychology

Martha J. Farah

Carnegie-Mellon University

DEPARTMENT
of
PSYCHOLOGY



DTIC
ELECTE
AUG 24 1987
S D

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

Carnegie-Mellon University

87 8 21 012

(11)

Is visual imagery really visual?
Overlooked evidence from neuropsychology

Martha J. Farah
Carnegie-Mellon University

DTIC
ELECT
S AUG 24 1987 D
C D

To appear in **Psychological Review**

Approved for public release; distribution unlimited. Reproduction in whole or in part is permitted for any purpose of the United States Government.

The preparation of this report was supported by the Personnel and Training Research Programs, Psychological Sciences Division, Office of Naval Research, under Contract Number N00014-86-K-0094, Contract Authority Identification Number NR 170-0-1Y, as well as by NIH grants NS23458 and NS06209 and the Alfred P. Sloan Foundation.

AD-A183740

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

| | | | | |
|---|---|--|--|---|
| 1a REPORT SECURITY CLASSIFICATION Unclassified | | | 1b RESTRICTIVE MARKINGS | |
| 2a SECURITY CLASSIFICATION AUTHORITY | | | 3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited. | |
| 2b DECLASSIFICATION/DOWNGRADING SCHEDULE | | | | |
| 4 PERFORMING ORGANIZATION REPORT NUMBER(S) Technical Report ONR-87-14 | | | 5 MONITORING ORGANIZATION REPORT NUMBER(S) | |
| 6a NAME OF PERFORMING ORGANIZATION Carnegie Mellon University | 6b OFFICE SYMBOL (if applicable) | 7a NAME OF MONITORING ORGANIZATION Personnel and Training Research Programs Office of Naval Research (Code 1142PT) | | |
| 6c ADDRESS (City, State, and ZIP Code) Department of Psychology Pittsburgh, PA 15213 | | 7b ADDRESS (City, State, and ZIP Code) 800 North Quincy Street Arlington, VA 22217-5000 | | |
| 8a NAME OF FUNDING/SPONSORING ORGANIZATION | 8b OFFICE SYMBOL (if applicable) | 9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER N00014-86-0094 | | |
| 8c ADDRESS (City, State, and ZIP Code) | | 10 SOURCE OF FUNDING NUMBERS | | |
| | | PROGRAM ELEMENT NO 61153N | PROJECT NO RR04208 | TASK NO RR042081 WORK UNIT ACCESSION NO 170-0-1Y |
| 11 TITLE (Include Security Classification) Is visual imagery really visual? Overlooked evidence from neuropsychology. | | | | |
| 12 PERSONAL AUTHOR(S) Farah, M.J. | | | | |
| 13a TYPE OF REPORT Technical | 13b TIME COVERED FROM _____ TO _____ | 14 DATE OF REPORT (Year, Month, Day) August 7, 1987 | 15 PAGE COUNT | |
| 16 SUPPLEMENTARY NOTATION To appear in <u>Psychological Review</u> | | | | |
| 17 COSATI CODES | | | 18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number) | |
| FIELD | GROUP | SUB-GROUP | | |
| 05 | 09 | | Visual cognition, mental imagery, neural bases of cognition. | |
| 19 ABSTRACT (Continue on reverse if necessary and identify by block number) Does visual imagery engage some of the same representations used in visual perception? The evidence collected by cognitive psychologists in support of this claim has been challenged by three types of alternative explanations: <i>tacit knowledge</i> , according to which subjects use nonvisual representations to simulate the use of visual representations during imagery tasks, guided by their tacit knowledge of their visual systems; <i>experimenter expectancies</i> , according to which the data implicating shared representations for imagery and perception is an artifact of experimenter expectancies; and <i>nonvisual spatial representation</i> , according to which imagery representations are partially similar to visual representations in the way they code spatial relations but are not visual representations. This article reviews previously overlooked neuropsychological evidence on the relation between imagery and perception, and discusses its relative immunity to the alternative explanations listed above. This evidence includes electrophysiological and cerebral blood flow studies localizing brain activity during imagery to cortical visual areas, and parallels between the selective effects of brain damage on visual perception and imagery. Because these findings cannot be accounted for in the same way as traditional cognitive data using the alternative explanations listed above, they can play a decisive role in answering the title question. | | | | |
| 20 DISTRIBUTION AVAILABILITY OF ABSTRACT <input type="checkbox"/> UNCLASSIFIED UNLIMITED <input checked="" type="checkbox"/> SAME AS REPORT <input type="checkbox"/> OTHER USERS | | | 21 ABSTRACT SECURITY CLASSIFICATION Unclassified | |
| 22a NAME OF RESPONSIBLE INDIVIDUAL Dr. Susan Chipman | | | 22b TELEPHONE (Include Area Code) (202)696-4318 | 22c OFFICE SYMBOL ONR 1142PT |

Abstract

Does visual imagery engage some of the same representations used in visual perception? The evidence collected by cognitive psychologists in support of this claim has been challenged by three types of alternative explanation: *Tacit knowledge*, according to which subjects use nonvisual representations to simulate the use of visual representations during imagery tasks, guided by their tacit knowledge of their visual systems; *experimenter expectancy*, according to which the data implicating shared representations for imagery and perception is an artifact of experimenter expectancies; and *nonvisual spatial representation*, according to which imagery representations are partially similar to visual representations in the way they code spatial relations but are not visual representations. This article reviews previously overlooked neuropsychological evidence on the relation between imagery and perception, and discusses its relative immunity to the alternative explanations listed above. This evidence includes electrophysiological and cerebral blood flow studies localizing brain activity during imagery to cortical visual areas, and parallels between the selective effects of brain damage on visual perception and imagery. Because these findings cannot be accounted for in the same way as traditional cognitive data using the alternative explanations listed above, they can play a decisive role in answering the title question.

| | |
|--------------------|-------------------------------------|
| Accession For | |
| NTIS CRA&I | <input checked="" type="checkbox"/> |
| DTIC TAB | <input type="checkbox"/> |
| Unannounced | <input type="checkbox"/> |
| Justification | |
| By | |
| Date in 1971 | |
| Availability Codes | |
| Dist | Availability Codes |
| A-1 | |



Is visual imagery really visual? Overlooked evidence from neuropsychology

Introduction

The question of whether visual imagery is really visual, that is whether it involves some of the same representations of stimuli normally engaged by the perception of those stimuli has been the subject of a long-standing debate in cognitive psychology. This paper reviews a set of empirical findings from neuropsychology that are directly relevant to this debate. I will argue that this generally overlooked source of data can play an important role in determining the relation between imagery and perception, because it is immune to many of the criticisms and alternative explanations that have plagued the cognitive psychology approach to this topic.

One side of the debate maintains that imaging consists of the top-down activation of perceptual representations, that is, representations that are also activated automatically by an external stimulus during perception. This idea dates back at least as far as the philosophical writings of Hume (1739/1969) and has been put forth more recently by Hebb (1968), Shepard (1978, 1984) and Finke (1980). In contrast, the other side of the debate maintains that the representations used in imagery are not the representations used in perception, and that the recall of visual information, even when accompanied by the phenomenology of "seeing with the mind's eye," is carried out using representations that are distinct from those used in veridical seeing (Pylyshyn, 1973; 1978; 1984, ch. 8).

What is at stake in this debate, that it should continue to be a focus of research and discussion on mental imagery? To begin with, it is a basic question about the representations underlying mental imagery, and on these grounds alone it warrants focussed attention from cognitive psychologists. In an early and influential critique of imagery research Pylyshyn (1973) concurred with imagery researchers that this issue is central. Atwood (1971) is quite right when he states, "The most elementary question that can be asked

about mnemonic visualization is the following: does the mnemonic image actually involve the visual system?" A decade and a half of active research on this issue has ensued (see Finke, 1985, for a recent review). The resolution of this controversy would also have broader implications beyond our understanding of mental imagery per se. For example, if visual imagery does engage visual perceptual representations, then at least some perceptual representations are not "informationally encapsulated" (see Fodor, 1983) insofar as they may take input from higher cognitive processes (i.e. imagery) as well as from bottom-up perceptual processes triggered by external stimuli. Furthermore, such a conclusion would imply that thinking in images involves representations (in the perceptual system) that are distinct from the representations used in nonimagistic thought, in turn implying a modular structure for the representations underlying thought (cf. Anderson, 1983; Fodor, 1983).

In discussing the theoretical implications of the relation between imagery and perception, it is worth noting explicitly an issue for which this relation has no direct implications, namely the issue of the format of mental images. Claims that images are pictorial or descriptive, array-like or propositional, analog or symbolic, are all claims about the format of images. As Block (1983) has pointed out, the relation of imagery to perception and the format of mental imagery are issues which are often conflated but are in principle independent. The finding that imagery shares representations with perception would not imply that imagery is pictorial, both imagery and perception might be descriptive. Furthermore, perceptual representations and mental images could have the same format (pictorial or descriptive) and yet be distinct representations.

Previous research in cognitive psychology Within cognitive psychology, several research programs have gathered evidence of common representations for imagery and perception. A comprehensive review of this work may be found in Finke (1985). A few representative examples of this large literature will be presented here.

Shepard's finding that shapes can be mentally reoriented only with a continuous

"mental rotation" provided an early demonstration of the apparently visuospatial properties of mental images (see, e.g., Shepard & Cooper, 1982). More recently, Shepard has explicitly related image rotation and other image transformations to the same mechanisms that underlie the visual perception of motion through comparative studies of image transformation and apparent motion (see, e.g., Shepard, 1984). In a separate series of studies with Podgorny (Podgorny & Shepard, 1978), he has demonstrated the functional equivalence of mental images and visual percepts in a dot localization task: Subjects viewed a square grid in which they either imagined or were presented with a block letter. On each trial a probe dot was presented somewhere in the grid and the subjects' task was to decide whether the dot fell on or off the (real or imagined) letter. Podgorny and Shepard found that the pattern of response times were highly dependent on the spatial position of the dot with respect to the letter. More importantly, the pattern of response times was essentially the same whether the letter was real or imagined, as would be expected if images and percepts of the letters activated common representations.

Kosslyn's (1980) studies of mental imagery have been primarily aimed at elucidating the format of mental images and other information-processing characteristics of mental imagery, but some of his findings nevertheless bear on the relation between imagery and perception. For example, the finding that images have a limited resolution, such that two imaged points can only be brought so close before they fuse (Finke & Kosslyn, 1980) and the finding that they show the visual "oblique effect," such that lines can be imaged more closely spaced at a horizontal or vertical orientation than obliquely (Kosslyn, 1983, pp. 81-83) have been taken to imply that visual representations are being used.

Finke (e.g., 1980) has addressed the issue of the relation of imagery to perception directly in a series of striking experimental demonstrations of image-percept equivalence. He has found that mental images can function equivalently to visual percepts in producing visual-motor adaptation (1979) and an orientation-specific color adaptation known as the

McCollough effect (Finke & Schmidt, 1977, 1978). Furthermore, he has shown that the functions describing the relation between resolution and eccentricity in the (real or imagined) visual field are highly similar for images and percepts (Finke & Kosslyn, 1980; Finke & Kurtzman, 1981). Each of these demonstrations of image-percept equivalence is consistent with the claim that some of the same representations are being used in imagery and perception.

Alternative explanations of findings in cognitive psychology. The evidence cited above has not been viewed as decisive by all psychologists. Three different arguments have been put forth questioning the inferences that link the type of data collected by Shepard, Kosslyn and Finke to the conclusion that imagery shares representations with perception.

Pylyshyn (1981) has argued that subjects in imagery experiments may use general purpose cognitive processes (as opposed to specifically visual processes), along with tacit (i.e. unconscious) knowledge of how their visual systems behave, to simulate the use of their visual systems. Although the "tacit knowledge" account of imagery experiments was formulated by Pylyshyn initially as an alternative to claims about the pictorial format of images, it is equally powerful as an alternative to claims of shared representations for imagery and perception. For example, according to a tacit knowledge account, the amount of time it takes subjects to rotate an image from one orientation to another is linearly related to the angular difference between the two orientations not as Shepard (1984) has claimed, because visual mechanisms are being used which themselves evolved to perceive continuous rotational motion. Rather, subjects tacitly know that when they actually see an object changing its orientation it does so continuously and in an amount of time proportional to the angle through which it rotates. Believing their task to be one of simulating a visual experience, subjects therefore modulate their response times to conform with this tacit knowledge about perceived rotations. All of the evidence cited above in support of image-percept equivalence can in principle be accounted for in a similar way by assuming that

subjects have tacit knowledge of such properties of their visual system as its fields of resolution, the oblique effect, and various adaptation effects. In principle, without some independent way of verifying what subjects do and do not tacitly know about their own visual systems, we cannot exclude this type of alternative explanation of the large body of data in cognitive psychology showing visual properties of mental images.

The difficulty of replicating many of the more impressive findings of image-percept equivalence (Broerse & Crassini, 1980, 1981, 1984; Intons-Peterson & White, 1981) has led some psychologists to consider the role of experimenter expectancy effects in imagery research. For example, Intons-Peterson (1983) has contended that the experimental paradigms used to study the visual properties of imagery are sufficiently vulnerable to experimenter expectancy that much, if not all, of the data showing visual properties of images could be artifactual. In support of this claim, she manipulated the expectations of research assistants regarding the outcome of a series of experiments on the relation of imagery to perception, and found that this systematically affected the results of the experiments. It is important to note that the experimenter expectancy effects created by Intons-Peterson consisted of simple increases or decreases of imagery performance relative to perceptual performance, and not the precise quantitative similarities and interactions between imagery and perception that Finke, Shepard and Kosslyn have found. However, the published failures to replicate some of these findings, along with the fact that positive findings of image-percept equivalence have invariably been obtained by researchers who believe that imagery shares representations with perception, gives plausibility to Intons-Peterson's claim and makes it at present, impossible to reject.

A third challenge to the claim that visual imagery involves visual representations comes from research with congenitally blind subjects (Carpenter & Eisenberg, 1978; Kerr, 1983; Marmor & Zabeck, 1976; Zimler & Keenan, 1983). In these studies, subjects who were blind from birth have been found to perform virtually normally on tasks such as image

rotation, inspection, and scanning (in some of which tactile stimuli were substituted for the usual visual stimuli). For example, one of the tasks that Kerr (1983) adapted from the imagery literature was based on Kosslyn's (1975) image inspection task, in which he manipulated the size at which people imaged a given object by having them image it to scale next to an elephant (in which the case the image was small) or a fly (in which case the image was large). Kosslyn found apparent visual resolution effects: subjects took longer to "see" the parts of objects in small images than in large. Kerr instructed her congenitally blind subjects to image a familiar household object either next to a car or next to a paperclip, and then measured how long it took them to search their image for a particular named part, such as the dial on a radio. Just as Kosslyn had found with sighted subjects, Kerr found slower response times to find the named parts when the images were small. Her conclusion was that the representations used in imagery do indeed have spatial properties, like visual representations, but they need not be visual themselves: in fact, with the congenitally blind subjects they were certainly not visual. These and similar findings with congenitally blind subjects pose the following general problem for interpreting the results of the larger imagery literature with sighted subjects: If the reaction time effects observed by Kosslyn, Shepard, Finke and others in visual imagery tasks can be observed in similar tasks with subjects who, because they have never seen, could not possibly be using visual information, then it is possible that the findings in sighted subjects are also due to the use of nonvisual spatial representations (cf. Baddeley & Leiberan 1980; Neisser & Kerr 1973).

The criticisms and alternative explanations of imagery research cited above are either in practice difficult or in principle impossible to reject using the conventional methods of cognitive psychology. For example, no matter how subtle and unexpected a perceptual property (like an acuity function) can be shown to manifest itself in imagery, we cannot, in principle, know that subjects are not using tacit knowledge about this property of their visual systems. Tacit knowledge accounts may be more or less plausible, but for any conceivable

finding of similarity between imagery and perception in a cognitive psychology experiment they will always be possible. Experimenter expectancy effects do not hold the same in principle invulnerability to all possible data, but at present they are impossible to reject as virtually all of the published experiments on image-percept equivalence (along with most other experiments in cognitive psychology, of course) could conceivably have permitted the transmission of experimenter expectancies to the subjects. Finally the research on imagery in the congenitally blind calls our attention to the existence of nonvisual representations with spatial properties similar to visual representations, which could in principle account for all of the findings so far attributed to the "visual" properties of imagery.¹

We are therefore in a theoretical stalemate over the issue of the relation between imagery and perception: All of the experimental results in cognitive psychology that were initially taken to support the existence of shared representations for imagery and perception are now seen to be open to each of three different types of alternative explanation. One approach to breaking this stalemate would be to carry out another body of experiments similar to the ones just described but which use naive experimenters (to rule out experimenter expectancy effects), which involve properties of the visual system not shared with nonvisual representational systems (e.g. color, binocular effects, to rule out the use of amodal spatial representations) and which involve properties so subtle that tacit knowledge accounts become unacceptably strained. A different approach would be to find a qualitatively new type of evidence for image-percept equivalence that is not susceptible to the three alternative explanations just discussed. The aim of this paper is to present just such a new type of evidence. First the evidence will be reviewed, and then its implications for the relation between imagery and perception will be discussed. It will be argued that this

¹ The effects of imagery on perception are a clear case for a common rather than a modal spatial representation. Interestingly, no such effects have been found (see R. Nelson, 1981). In fact, Finke's imagery-induced McCollough effect is obtained only for imaged lines on a real colored background, and not for imaged colors on a real black and white grating.

source of evidence has a special status in the debate over imagery and perception. It has the ability to be decisive in the face of the alternative accounts discussed above, where the conventional data of cognitive psychology data do not.

Evidence from neuropsychology

A considerable number of findings from neuropsychology are relevant to the relation between imagery and perception, although even within neuropsychology there seems to be little awareness of the quantity and coherence of these many separate findings. The importance of this evidence is that it expands qualitatively, as well as quantitatively, the support for visual perceptual mechanisms in visual mental imagery. The relevant findings in neuropsychology can be roughly grouped into two categories: those that implicate the use of visual processing areas of the brain in visual imagery, and those that implicate shared functional mechanisms for visual imagery and visual perception, above and beyond the fact that they share common brain regions.

Common neural substrates for imagery and perception. Cortical visual processing begins in the occipital lobes which contain primary and secondary visual cortex, and continues in the posterior parietal and temporal lobes which contain modality-specific visual representations as well as multimodal representations. The earliest suggestion that imagery might involve the use of the visual areas of the brain came from case reports of cortically blind patients. Cortical blindness is loss of vision due to destruction of the occipital cortex. Many of these patients appear unable to use mental imagery despite the relative preservation of other cognitive abilities (Brown, 1972; Symonds & MacKenzie, 1957). A systematic assessment of imagery ability in cortically blind patients with well-localized lesions could in principle provide strong evidence on the relation between the neural substrates of visual imagery and visual perception. In practice, however, the documented cases do not provide sufficiently detailed information about the patients' impaired and intact cognitive

abilities to be more than suggestive.

Stronger evidence that parts of the visual cortex participate in visual imagery comes from the use of regional cerebral blood flow and electrophysiological techniques for measuring and localizing brain activity in normal subjects. Regional cerebral blood flow provides a spatially precise method of measuring regional brain activity in normal humans, with increased blood flow indexing increased activity. Roland and Friberg (1985) examined regional cerebral blood flow while subjects rested and during three cognitive tasks: mental arithmetic (subtracting 3's starting at 50), memory scanning of an auditory stimulus (mentally jumping every second word in a well-known musical jingle), and visual imagery (visualizing a walk through one's neighborhood making alternating right and left turns starting at one's front door). Subjects were periodically queried as to their current answer (i.e. the number they were on in the mental arithmetic task, the word they were on in the auditory rehearsal task, and the location they were at in the imagery task). This procedure yielded error rates, from which the authors concluded that the three tasks were equally difficult. In each of the 11 normal subjects tested, the pattern of blood flow in the visual imagery task showed massive activation of the posterior regions of the brain compared to the resting state, including the occipital lobe (the visual cortex proper) and posterior superior parietal and posterior inferior temporal areas important for higher visual processing. These are the same areas that normally show increased blood flow during visual-perceptual tasks (Mazziotta, Phelps & Halgren, 1983; Roland, 1982; Roland & Skinhoj, 1981). Furthermore, these areas did not show increases in blood flow compared to the resting state in the other two cognitive tasks.

The Roland and Friberg results demonstrate visual cortical involvement in a fairly complex imagery task that includes both visualizing scenes from memory and transforming them (at each turn in the imaginary walk). Goldenberg, Podreka, Steiner, and Willmes (in press, a) devised a simpler imagery task, along with a control task differing from the

imagery task only in the absence of imagery. Different groups of normal subjects were given the same auditorily-presented lists of concrete words to learn under different instructional conditions: one group was told to just listen to the words and try to remember them, while the other group was told to visualize the referents of the words as a mnemonic strategy. Some subjects in the no-imagery group reported spontaneously imaging the words when questioned after the experiment, and they were re-classified as image condition subjects. Recall was higher overall for the imagery group, as would be expected if these subjects did indeed differ from the no-imagery group in their use of imagery. The patterns of blood flow recorded during the two conditions also differed, by two distinct measures. First, there was relatively more blood flow to the occipital lobes in the imagery condition than in the nonimagery condition in which the identical stimulus words were being memorized. Second, the pattern of covariation of blood flow among brain areas (calculated by a Smallest Space Analysis, Lingoes, 1979), which provides another index of regional brain activity, was also greater in the occipital and posterior temporal areas of the brain in the imagery condition compared to the nonimagery condition.

Goldenberg, et al. (in press, b) compared the patterns of regional blood flow while subjects tried to answer two types of questions. Questions that require visual imagery to answer (e.g. "Is the green of pine trees darker than the green of grass?") and questions that do not require imagery to answer (e.g. "Is the categorical imperative an ancient grammatical form?"). Despite the superficial similarity of the two types of task, answering "yes/no" general knowledge questions, they differed significantly in the patterns of regional cerebral blood flow they evoked. The imagery questions caused significantly greater bloodflow than the nonimagery questions. The results of the Smallest Space Analysis also implicated occipital activity in the imagery condition, as well as revealing activity in the posterior temporal and parietal visual processing areas. In contrast, the nonimagery condition did not reveal visual area activation.

Might the increased visual area activity in Goldenberg et al.'s imagery tasks merely index greater effort by subjects in those tasks than in the nonimagery control tasks? This is unlikely for three reasons. First, task effortfulness is generally reflected in blood flow changes to the frontal lobes, and has not been observed to produce occipital changes (Ingvar & Risberg, 1967; Lassen, Ingvar & Skinhoj, 1978). Second, subjects in the first experiment who were given the more effortful task of memorizing lists of abstract words, rather than concrete words, under the same task conditions with no imagery instructions, did not show increased occipital blood flow. Third, whereas the imagery condition of Goldenberg et al.'s first experiment involved more effortful processing than the nonimagery condition, the imagery condition of Goldenberg et al.'s second experiment was easier than the nonimagery condition (as evidenced by the lower error rates).

In three very different experimental paradigms, one a rather open-ended request to visualize a walk through familiar territory, another a verbal list-learning task in which imagery use was manipulated by explicit instructions, and the third a question-answering task in which imagery use was manipulated by implicit differences in the nature of the questions, convergent findings emerged. In each case the imagery induced blood flow to the visual areas of the brain. Furthermore, in the two latter studies, the imagery conditions differed minimally from the comparison conditions, which did not show these increases.

Further evidence that the visual cortex participates in visual imagery comes from electrophysiological techniques: EEG (electroencephalography) and ERP (event-related potentials). In EEG techniques, suppression of alpha rhythm (EEG activity in a certain range of frequencies) is associated with increased brain activity. Many authors have found that visual imagery is accompanied by alpha rhythm attenuation over the visual areas of the brain (Barratt, 1956; Brown, 1966; Davidson & Schwartz, 1977; Golla, Hutton & Grey Walter, 1943; Short, 1953; Slatter, 1960). Unfortunately, a methodological flaw in most of these studies is the lack of control for the degree of overall mental effort involved in the visual imagery and

comparison conditions. However, the study of Davidson and Schwartz (1977) does contain the appropriate control measures and provides a clear and elegant demonstration of the modality-specific nature of the brain activity underlying imagery: Davidson and Schwartz measured the EEG alpha rhythm simultaneously over the visual (occipital) and tactile (parietal) areas of the brain, during visual imagery (imagining a flashing light), tactile imagery (imagining one's forearm being tapped) and during combined visual and tactile imagery (imagining the flashes and taps together). Whereas there was no difference in total alpha attenuation between the visual and tactile imagery conditions (i.e. the overall effects of tactile and visual imagery on general effort and arousal were the same), the site of maximum alpha attenuation in the visual imagery condition was over the visual areas and the site of maximum alpha attenuation in the tactile imagery condition was over the tactile areas. Alpha attenuation in the combined visual and tactile imagery condition showed a more balanced pattern of distribution across both visual and tactile areas.

Recent work using event-related potential techniques offers another electrophysiological window on the areas of the brain engaged during imagery. ERP differs from EEG in that it measures just the electrical activity of the brain that is synchronized with (and thus presumably "related" to) the processing of a stimulus. Farah, Peronnet, Weisberg & Perrin (1987) measured the ERP to visually presented words under two different instructional conditions: Simply reading the words, and reading the words and imaging their referents (e.g. if the word is "cat," imaging a cat). The words were presented for 200 milliseconds each. ERPs were recorded from sixteen standard sites on the scalp including occipital, parietal, temporal and frontal locations. The first 450 milliseconds of the ERPs in both conditions were indistinguishable, reflecting their common visual and lexical processing stages. However, later components of the two conditions differed from one another. In the imagery condition there was a highly localized increase in positivity of the ERP relative to the "reading only" condition, at the occipital electrodes, implicating occipital activity during

the process of imaging. Scalp current density analyses of the ERP data, which provide enhanced localization (Perrin, Bertrand & Pernier, 1986) revealed a central occipital current source and lateral occipital current sinks, consistent with ERP generators in occipital cortex, and two occipito-temporal current sources and lateral fronto-temporal current sinks, consistent with an ERP generator in each temporal lobe.

Is it possible that this occipital ERP reflects general effects of cognitive load, and is not specifically related to imagery? To test this possibility, subjects were presented with a new task, the misspelling detection task, which involved the same stimuli presented under the same conditions as the previous experiment. In this experiment, we compared the "reading only" of correctly spelled words to the detection of occasional misspellings, an effortful visual task using the same stimuli as the imagery task (except that about one in eight words was misspelled). The difference between the ERPs from reading and misspelling detection showed a different polarity as well as a different temporal and spatial distribution compared to the imagery effect observed earlier. This effect consisted of increased negativity rather than positivity, affecting a broader region of the posterior scalp (extending to the anterior temporal electrodes), and peaking about 200 milliseconds earlier. Therefore, the focal occipital positivity observed when subjects form images is not merely a manifestation of a general "visual effort" effect on the evoked potential, but is tied more specifically to the processes taking place in the imagery condition of the experiment. Furthermore, when the imagery condition was changed in a subsequent experiment from one in which the subject images a different object from memory on each trial to the repeated imaging of a small set of line drawings that subjects memorized just before ERP recording, the same focal occipital positivity ensued.

Farah, Peronnet, Gonor, Giard & Perrin (1987) took a different approach to localizing mental imagery in the brain using event-related potential techniques, by examining the effect of imagery on the ERP to visual stimuli. Subjects were instructed to image stimuli while

they being presented with real stimuli, so that we could observe the effect of imagery on the ERP to stimuli. We reasoned that if imagery has a systematic effect on the ERP to stimuli, then there must be some common brain locus at which imagery and perceptual processing interact. More importantly, if the interaction between imagery and perception is content-specific -- that is, for example, if imaging an H affects the ERP to H's more than the ERP to T's, and imaging a T affects the ERP to T's more than the ERP to H's -- then that interaction must be taking place at some locus where information about the differences between H's and T's is preserved, that is, at a representational locus. In this experiment subjects imaged H's and T's, while performing a detection task in which an H, a T, or no stimulus was presented on each trial. The image that the subject was instructed to form on a given trial was nonpredictive of the upcoming stimulus. The ERPs to H's and T's while subjects imaged the same letter were compared to the ERPs to H's and T's while subjects imaged the other letter. In this way, we could observe the content-specific effect of imagery on the visual ERP, while holding constant the actual stimuli to which the ERPs were recorded (equal numbers of H's and T's in both conditions) and the effort of forming and holding an image (equal numbers of H and T images in each condition). If there is a content-specific effect of imagery on the visual ERP, then by localizing it we can put constraints on the location of representations accessed by both imagery and perception.

Imagery had a content-specific effect on the evoked potential within the first 200 milliseconds of stimulus processing, and this effect was localized at the occipital recording sites. Furthermore, the inference that the underlying brain location of the image-percept interaction is occipital is strengthened by the fact that the timecourse of the effect of imagery on the ERP is the same as that of the first negative peak of the visual ERP waveform, which is believed to originate in occipital cortex (Leseure & Joseph, 1980; Alain, Dagnelie, Spekrijse & Van Dijk, 1987). The finding that an effect is maximal just when an ERP component is maximal implies that the neural locus of the effect is one or more of the

generators of the ERP component. Scalp current density mapping provided converging evidence of the visual cortical locus of this effect, showing a central occipital current sink and two lateral posterior current sinks and diffuse (and therefore probably distant) frontal current sources. This configuration of current sources and sinks is consistent with an occipital and posterior temporal locus for the content-specific effect of imagery on perception.

To sum up the relevant electrophysiological literature, two measures, EEG and ERP have been used in a variety of experiments involving imagery. In all cases, imagery activity was localized to the occipital regions. Furthermore, in a subset of this body of experiments (Davidson & Schwartz, 1977; Farah, Peronnet, Weisberg & Perrin, 1987; Farah, Peronnet, Gonon, Giard & Perrin, 1987), control conditions were included which allow us to assess the cognitive specificity of these electrophysiological effects, and in each case they were associated with visual imagery activity *per se*. The electrophysiological evidence is thus in agreement with results from a very different methodology, regional cerebral blood flow, in implicating occipital activity during imagery. Across a variety of tasks, it has been found that imagery engages visual cortex whereas other tasks, many of which are highly similar save for the absence of visual imagery, do not.

The most straightforward and parsimonious conclusion from this pattern of results is that mental images are visual representations—that is, they consist at least in part of some of the same representations used in vision. However, there does exist a logically correct alternative explanation according to which mental images are not visual representations but are merely accompanied by activation in visual brain areas. On this account, the visual area activation is epiphenomenal with respect to the functions of imagery. To distinguish between these alternatives, we must find out whether destruction of visual brain areas results in imagery impairments as well as visual impairments. Parallel impairments in imagery and perception after brain damage imply that the visual areas implicated in the localization

studies reviewed above do play a functional role in imagery, whereas the finding that imagery is unimpaired in patients with visual disorders following brain damage implies that activation of visual areas during imagery is epiphenomenal. The data reviewed in the next section allow us to distinguish between a functional and an epiphenomenal role for the visual system in imagery by reporting the effects of damage to the visual system on imagery ability. In addition, these data add quantitatively to the accumulating evidence for the involvement of the visual system in mental imagery.

Functional parallels between imagery and perception after brain damage. The existence of highly selective deficits in visual abilities has contributed to our understanding of the functional architecture of visual perception by demonstrating which perceptual abilities are independent of which other abilities. If visual imagery uses the same representational machinery as visual perception, then one should expect selective deficits in the imagery abilities of patients that parallel their selective perceptual deficits. In fact, for all of the types of selective visual deficits due to cerebral lesions in which imagery has been examined, parallel imagery deficits have been observed. These studies are summarized below.

At early stages of cortical visual processing, color is represented separately from other visual stimulus dimensions, and brain damage affecting the cortical visual areas can therefore result in relatively isolated color vision deficits (see Cowey, 1982; Meadows, 1974). A long history of the case by case study of patients with acquired cerebral color blindness has documented an association between loss of color perception and loss of color imagery (e.g. Beauvois & Saillant, case 2, 1985; Heidenhain, 1927; Riddoch & Humphreys, in press; Jossman, 1929; Lewandowsky, 1908; Pick, 1908; Stengel, 1948). In addition to being unable to identify or discriminate among colors, these patients cannot report the colors of common objects from memory (e.g. the color of a football, cactus, or German Shepherd's back), a task which most people find requires imaging the object in color. These patients are not

generally impaired in their cognitive functioning; in fact, Riddoch & Humphreys (in press) documented good general imagery ability (assessed by drawings and descriptions of objects from memory) in their color-blind patient who had impaired color imagery. The implication of this association between the perception of color and imagery for color is that the two abilities depend upon the same neural substrates of color representation.

DeRenzi and Spinnler (1967) pointed out the need for a more systematic study of color-related impairments after brain damage, and undertook a large group study of unilaterally brain-damaged patients in which they assessed color vision and color imagery. Color vision was tested in two ways: Having the patient sort a set of colored paper squares into pairs having the same color, and having the patient name or trace out the digit embedded in random dots which are segregated into digit and background only by color (the "Ishihara" test of color blindness). Color recall was also tested in two ways: Having the patient respond verbally to questions of the form "What color is a tangerine?", "What color is cement?," and having the patients color black and white line drawings of objects with their characteristic color chosen from a set of colored crayons. DeRenzi and Spinnler found that patients who had impaired color vision also had impaired color imagery. Perhaps it is not surprising that a patient with a color vision deficit would perform poorly on the coloring task, in which color vision is needed to select the appropriate crayon, or that patients with language or memory impairments would do poorly on a verbal task of color memory. However, the relationship between color vision impairment and color imagery impairment held high statistical significance even when patients who were neither language-impaired or memory-impaired were considered on just the verbal test of color imagery.

Another source of evidence that color is represented by the same neural structures in imagery and perception comes from an intriguing case study by Beauvois and Saillant (case 1, 1985) of a patient whose visual areas had been neuroanatomically disconnected from her language areas by a stroke. The patient was able to perform color tasks that were purely

visual, such as sorting objects on the basis of color and identifying the embedded characters in the Ishihara test of color blindness, because her visual areas had not been damaged. Her general verbal ability was also quite intact, as evidenced by a verbal IQ score of 123, because her language areas had not been damaged. However, if the task involved coordinating a visual and verbal representation, for example naming a visually-presented color or pointing to a named color, her performance was extremely poor, owing to the neuroanatomical disconnection between her language and vision areas. The patient was tested on various color memory tasks, including two similar to those of DeRenzi and Spinnler: viewing correctly and incorrectly colored drawings of objects and distinguishing between them, and answering verbally posed questions about the color of common objects of the form "What color is a -- ?". The patient was able to perform the purely visual color memory task, implying that her mental images of colored objects were not disconnected from the visual areas used in recognizing and discriminating among the colored pictures. Her performance on the verbally posed color questions depended upon the nature of the question: For questions that made use of verbal associations between objects and colors (e.g. "What color is Paris ham?", where "Paris ham" is also called "white ham"; or "What color is envy?") the patient performed normally. In contrast, for questions that appear to require mental imagery (e.g. "What color is a gherkin?") she performed poorly. Again, this implies that whereas verbal memory associations for colors were not disconnected from the language areas of this patient with visual-verbal disconnection, imagistic representations of color were. Finally, Beauvois directly manipulated whether the patient used imagery or nonimagistic memory representations for retrieving the same information. In one condition she asked questions such as "You have learnt what color snow is. It is often said: 'What do people say when they are asked what color snow is?' or 'It is winter. Imagine a beautiful snowy landscape. Can you see it? Well, now tell me what color the snow is." The patient performed normally when biased toward a verbal recall strategy, and her

performance dropped significantly when biased toward an imagery recall strategy. This is again what one would expect to find if the color of mental images is represented in the same neural substrate as the color of visual percepts.

In sum, three types of evidence support the hypothesis that imaging an object in color requires some of the same neural representations necessary for color vision: Individual cases of acquired central color blindness are reported to have lost their color imagery, in a group of patients with varying degrees of color vision impairment color imagery is correlated with color vision, and in a case of visual-verbal disconnection, images were equivalent to visual representations in terms of their interactions with other visual and verbal task components.

Patients with bilateral parieto-occipital disease often have trouble knowing *where* an object is in the visual field, without any difficulty identifying *what* the object is (De Renzi, 1982). The impairment in the localization of stimuli in space may be quite selective to the visual modality, so that these patients can orient to tactile and auditory stimuli. At the same time, these patients are unimpaired in their ability to recognize of visual stimuli. Thus such a patient may quickly identify an object such as a postage stamp held somewhere in his or her visual field but be unable to indicate its position either verbally or by pointing. Other patients, with bilateral temporo-occipital disease, may show the opposite pattern of visual abilities (Bauer & Rubens, 1985). They are impaired in their ability to recognize visually presented stimuli, despite adequate elementary visual capabilities (e.g. size of visual field, acuity), and their failure of recognition is modality-specific. They are able to recognize objects by touch or by characteristic sounds. Furthermore, their ability to localize visually presented objects is unimpaired. Thus, such a patient might fail to recognize a postage stamp by sight, but could accurately point to its location. This dissociation is evidence for a rather counter-intuitive division of labor in the visual system between the localization of stimuli and their identification, an idea which is also supported by animal experimentation.

(Ungeleider & Mishkin, 1982). Levine, Warach and Farah (1985) studied the imagery abilities of a pair of patients, one with visual localization impairment after bilateral parieto-occipital damage and one with visual object identification impairment after bilateral temporo-occipital damage, with special attention to the distinction between spatial *location* information and single object *appearance* information in visual images. We found that the preserved and impaired aspects of vision in each patient were similarly preserved or impaired in imagery. The patient with object identification difficulties was unable to draw or describe the appearances of familiar objects, animals and faces from memory, despite being able to draw and describe in great detail the relative locations of cities and states on a map, furniture in his house, and landmarks in his city. The patient with object localization difficulties was unable to describe the relative locations of landmarks in his neighborhood, cities in the United States, or, when blindfolded, to point to furniture in his hospital room. He was, however, able to give detailed descriptions of the appearance of a variety of objects, animals and faces. In a review of the literature for similar cases, we found that for a majority of the published cases of selective visual "what" or "where" deficit, when the appropriate imagery abilities were tested they showed parallel patterns of imagery deficit and in no case was there a well-documented violation of this parallelism. Of 28 cases of object identification difficulties in the literature 14 were reported to have parallel imagery impairments, six were not examined regarding imagery, and three were reported to have intact imagery. For all three of this last group of patients, the authors of the case reports relied exclusively on the patients' own introspective assessments of their imagery ability. Of 26 cases of visual disorientation, imagery for spatial relations was tested in only twelve, and in nine of these cases it was found to be defective. Of the remaining three, the information concerning their imagery consisted of in one case having "good memory for paths in the city" with no other details given, in another case being able to "describe a geographic map" and in a third being able to describe the ward plan accurately. This third patient

was unusual for a case of visual disorientation in that she was able to find her way about

Dissociations between object recognition abilities *within* the temporo-occipital "what" system also exist. The most selective deficit of this type consists of profoundly impaired face recognition with roughly intact recognition of other classes of visual stimuli as well as intact general intellectual and memory functioning (Bauer & Rubens, 1985). In general, the particular classes of stimuli that are hardest for such patients to recognize are also the hardest for these patients to visualize from memory, as assessed by either drawings or descriptions from memory, or by patients' introspective reports. For example, Shuttleworth Syring and Allen's (1982, case 2) patient who had a selective face recognition deficit was also reported to "have no voluntary visual recall (revisualization) of faces but was able to revisualize more general items such as buildings and places." Shuttleworth et al reviewed the literature for cases of face recognition deficit, and found that approximately 40% of 74 cases reported impairments in face imagery. They went on to caution that in many of the cases in which face imagery was not noted to be impaired "the accuracy of the image could not be ascertained and was seriously questioned in a number of cases." Beyn and Knyazeva (1962) compared, on an item by item basis, the visual imagery and visual recognition abilities of a patient with face recognition difficulties. They found a close association between the particular visual stimuli that could be recognized and imaged: the patient recognized three out of 16 objects that he was unable to image, and 13 out of 16 objects that he could image.

Patients with right parietal lobe damage often fail to detect stimuli presented in the left half of the visual field even though their elementary sensory processes for stimuli on the affected side of space are intact (Heilman, Watson, & Valenstein, 1985; Posner, Walker, Friedrich & Rafal, 1984). This deficit is known as "visual neglect" and also appears to manifest itself in visual imagery. Bisiach and his colleagues (Bisiach & Luzzatti, 1978; Bisiach, Luzzatti and Perani, 1979) have shown that right parietal patients with visual neglect

also fail to access the left sides of imagined objects and scenes. In Bisiach and Luzzatti's initial report, two right parietal lobe-damaged neglect patients were asked to imagine viewing a famous square in Milan (the Piazza del Duomo, with which the patients had been familiar before their brain damage) from a particular vantage point, and to describe the view. Both patients omitted from their descriptions the landmarks that would have fallen on the left side of that scene. The patients were then asked to repeat the task, this time from the opposite vantage point, from which the buildings, statues and other landmarks that fell on the left side of the previous view were visible on the right, and vice versa. The patients' descriptions of their images now included the items that had previously been omitted, and omitted the items on the left side of their current image (which had before been reported).

Bisiach, Luzzatti & Perani followed up these case studies with a group study of neglect for visual images. Right parietal-damaged patients with left-sided neglect and a control group of patients without neglect were shown abstract cloud-like shapes passing behind a screen with a narrow vertical slit in the center. Because all of the stimulus input in this task is presented centrally in the visual field, any effect of left-sided neglect in this task cannot be attributed to perceptual neglect. After viewing pairs of such shapes, the patients were to decide whether the two members of the pair were identical or different. This presumably requires mentally reconstructing images of the stimuli from the successive narrow vertical views. Patients who neglected the left halves of visual stimuli also neglected the left halves of their images, as evidenced by a greater number of errors when pairs of shapes differed on their left sides than when they differed on their right sides in the task.

Discussion

We saw above that the evidence for visual mechanisms in imagery from cognitive psychology is susceptible to three specific lines of criticism. Can the same be said of the neuropsychological evidence summarized above? Let us review each of the alternative

explanations and attempt to apply them to the present data. A tacit knowledge account of the EEG and blood flow data, implicating the use of cortical visual areas during visual imagery activity, would need to include the following two assumptions: (1) That subjects know what parts of their brains are normally active during vision and (2) That subjects can voluntarily suppress alpha activity or increase regional blood flow to specific areas of their brains. It is clear that most subjects do not consciously know which brain areas are involved in vision, but what about the possibility of tacit knowledge? Tacit knowledge of the neural localization of visual processing would be impossible to acquire: Whereas one could conceive of mechanisms by which a subject might acquire tacit knowledge of many subtle functional properties of his or her visual system (by observing aftereffects, illusions, the relative difficulty of seeing different stimuli, etc.), there are no conceivable mechanisms by which a subject could gain tacit knowledge of the neuroanatomical locations of visual processing. The second assumption is also difficult to accept: whereas subjects can learn through biofeedback techniques to modulate EEG spectra, for example, untrained subjects cannot voluntarily change features of their EEG (Nowlis & Kamiya, 1970).

How would the tacit knowledge account explain functional parallels observed between perceptual and imaginal deficits after brain damage? As with normal subjects, the assumption would be made that the patients take their task to be behaving as if they were actually seeing the to-be-imagined stimuli. But this answer does not entirely constrain a prediction, because we do know whether patients who know they have visual deficits would behave as if they were seeing with normal visual systems (i.e. using their tacit knowledge of normal vision) or with their defective visual systems (i.e. using their more recently acquired tacit knowledge of their impaired vision). An independent basis for deciding between these two predictions comes from studies of subjects who were peripherally (as opposed to cortically) blinded late in life. These subjects perform essentially normally on visual imagery tasks (Hollins, 1985). In terms of a tacit knowledge account of performance in imagery

tasks, this implies that patients with visual deficits will interpret imagery tasks as demanding the simulation of intact visual processes. This leads to the prediction that patients with acquired visual disorders of cerebral origin should continue to perform normally in imagery experiments, a prediction which is clearly disconfirmed by the available evidence.

Even if we allow the assumption that, unlike the patients with peripheral visual disorders, the patients with central visual disorders make the strategic decision to tailor their imagery task performance to match their own, defective, perceptual performance, several problems remain for the tacit knowledge account. First, whereas normal subjects in imagery tasks would be modulating subtle properties of their responses (such as response latency) to simulate visual processes, patients would be feigning an inability to perform certain imagery tasks. It is somewhat implausible that patients would persist in failing easy tasks when they could be giving correct responses. Second, studies of malingering patients, who do intentionally perform poorly on neuropsychological tests, have shown that statistical naivete leads them to perform significantly worse than chance (Lezak, 1983), which is not the case with the patients in the studies reviewed above. A final difficulty with the tacit knowledge account is specific to the findings on visual neglect in imagery: most patients with visual neglect deny that they have any visual difficulty, and their behavior of leaving uneaten food on the left sides of their plates when they are hungry, injuring themselves by walking into objects on their left sides, and so on evinces a lack of even tacit knowledge of this deficit (Heilman et al., 1985). The two patients in Bisiach & Luzzatti's case studies were both unaware of their visual difficulty, and we may assume that if their group study included typical patients then these subjects too would have been unaware of their deficits. Nevertheless, and contrary to the tacit knowledge hypothesis, these patients demonstrated parallel deficits in their imagery performance.

Could experimenter expectancy have produced some or all of the neuropsychological evidence reviewed here? In the case of the observed parallels between perceptual and

imaginal deficits this possibility certainly exists, but is less likely than in the corresponding cognitive literature because of the wide range of investigators, whose work spans several decades before the current "imagery debate," and the majority of whom had no stated position on the issue of the relation between imagery and perception. Nonetheless, the effects of experimenter expectancy on this data cannot be strictly ruled out. In contrast, the EEG, ERP and blood flow findings represent psychophysiological measures which would be impossible to "shape" by the normal mechanisms of experimenter expectancy in psychological research. Unless we grant the two assumptions needed for a tacit knowledge account of these findings, namely that subjects know where their visual processing areas are and have the ability to tailor their EEG, ERP and blood flow accordingly, there is no way that instructions given prior to the recording of EEG, ERP or blood flow could produce the results actually obtained in these studies. For most of the studies, communication from the experimenters during the recording sessions could not affect the results through a biofeedback mechanism either. In most of the EEG studies (including Davidson & Schwartz, 1977), and in both of the ERP studies, subjects were isolated from the experimenters during data collection.

How do the neuropsychological results fit in with the observations that peripherally blind subjects can use imagery? Far from being at odds with one another, these two sets of findings together make clear the sense in which visual imagery is visual. Specifically, imagery is not visual in the sense of necessarily representing information acquired through visual sensory channels. Rather, it is visual in the sense of using some of the same neural representational machinery as vision. That representational machinery places certain constraints on what can be represented in images and on the relative ease of accessing different kinds of information in images. It is possible that peripherally blind subjects, like those blind from birth, can use their intact cortical visual areas for internal representation during imagery tasks. It is also possible to explain the performance of congenitally blind

subjects in imagery tasks in terms of nonvisual spatial representations, as Kerr and others have proposed, without being forced to suppose that normal subjects perform these tasks the same way. Given that the brain represents spatial information with both tactile and visual modality-specific representations, it is not unparsimonious to assume that normal subjects have a choice of using visual or nonvisual spatial representations for performing imagery tasks (cf. Davidson & Schwartz, 1977), and that the extent of a subject's visual experience or deprivation would determine which of these representations is chosen.

Acknowledgements

The author thanks Jennifer Brunn, Michael Corballis, Ron Finke, Clark Glymour, Margaret Intons-Peterson, Ross Thompson, and two anonymous reviewers for their helpful comments on an earlier draft of this paper. The writing of this paper was supported by ONR Contract No. N00014-86-K-0094, NIH grant NS23458, and by NIH Program Project Grant NS 06209-21 for the Aphasia Research Center of the Boston University School of Medicine.

References

- Anderson, J. R. (1983). *The architecture of cognition*. Cambridge, MA: Harvard University Press.
- Atwood, G. E. (1971). An experimental study of visual imagination and memory. *Cognitive Psychology*, 2, 290-299.
- Baddeley, A. D., & Lieberman, K. (1980). Spatial working memory. In *Attention and performance VIII*. Hillsdale, N.J.: Erlbaum.
- Barratt, P. E. (1956). Use of the EEG in the study of imagery. *British Journal of Psychology*, 47, 101-114.
- Bauer, R. M., & Rubens, A. B. (1985). Agnosia. In K. M. Heilman & E. Valenstein (Eds.), *Clinical Neuropsychology*. New York: Oxford University Press. 2nd edition.
- Beauvois, M.F., & Saillant, B. (1985). Optic aphasia for colours and colour agnosia: A distinction between visual and visuo-verbal impairments in the processing of colours. *Cognitive Neuropsychology*, 2(1), 1-48.
- Beyn, E. S., & Knyazeva, G. R. (1962). The problem of prosopagnosia. *Journal of Neurology, Neurosurgery and Psychiatry*, 25, 154-158.
- Bisiach, E., & Luzzatti, C. (1978). Unilateral neglect of representational space. *Cortex*, 14, 129-133.
- Bisiach, E., Luzzatti, C., & Perani, D. (1979). Unilateral neglect, representational schema and consciousness. *Brain*, 102, 609-618.
- Block, N. (1983). Mental pictures and cognitive science. *The Philosophical Review*, 92, 499-541.
- Broerse, J., & Crassini, B. (1980). The influence of imagery ability on color aftereffects produced by physically present and imagined induction stimuli. *Perception & Psychophysics*, 28, 560-568.
- Broerse, J. & Crassini, B. (1981). Misinterpretations of imagery-induced McCollough effects

- A reply to Finke. *Perception & Psychophysics*, 30, 96-98.
- Broerse, J., & Crassini, B. (1984). Investigations of perception and imagery using CAEs: The role of experimental design and psychophysical method. *Perception & Psychophysics*, 35, 153-164.
- Brown, B. B. (1966). Specificity of EEG photic flicker responses to color as related to visual imagery ability. *Psychophysiology*, 2(3), 197-207.
- Brown, J. W. (1972). *Aphasia, Apraxia and Agnosia: Clinical and Theoretical Aspects*. Springfield, IL: Charles C. Thomas.
- Carpenter, P. A., & Eisenberg, P. (1978). Mental rotation and the frame of reference in blind and sighted individuals. *Perception & Psychophysics*, 23, 117-124.
- Cowey, A. (1982). Sensory and non-sensory visual disorders in man and monkey. In D. E. Broadbent and L. Weiskrantz (Eds.), *The Neuropsychology of Cognitive Function*. London: The Royal Society.
- Davidson, R. J., & Schwartz, G. E. (1977). Brain mechanisms subserving self-generated imagery: Electrophysiological specificity and patterning. *Psychophysiology*, 14, 598-604.
- DeRenzi, E. (1982). *Disorders of space exploration and cognition*. New York: John Wiley & Sons.
- Farah, M. J., Peronnet, F., Gonon, M. A., Giard, M. H., & Perrin, F. (1987). Common pathways for mental imagery and perception. Manuscript submitted for publication.
- Farah, M. J., Peronnet, F., Weisberg, L. L., & Perrin, F. (1987). Brain activity underlying mental imagery: An ERP study. Manuscript submitted for publication.
- Finke, R. A. (1980). Levels of equivalence in imagery and perception. *Psychological Review*, 87, 113-132.
- Finke, R. A. (1985). Theories relating mental imagery to perception. *Psychological Review*, 92, 236-259.
- Finke, R. A., and Kosslyn, S. M. (1980). Mental imagery acuity in the peripheral visual field.

- Journal of Experimental Psychology Human Perception and Performance*, 6, 244-264
- Finke, R.A., and Schmidt, M.J. (1977). Orientation-specific color aftereffects following imagination. *Journal of Experimental Psychology Human Perception and Performance*, 3, 599-606.
- Finke, R.A., and Schmidt, M.J. (1978). The quantitative measure of pattern representation in images using orientation-specific color aftereffects. *Perception & Psychophysics*, 23, 515-520.
- Fodor, J. A. (1983). *The modularity of mind*. Cambridge, MA: The MIT Press.
- Goldenberg, G., Podreka, I., Steiner, M., and Willmes, K. (In press (a)). Patterns of regional cerebral blood flow related to memorizing of high and low imagery words -- an emission computer tomography study. *Neuropsychologia*.
- Goldenberg, G., Podreka, I., Steiner, M., and Willmes, K. (In press (b)). Regional cerebral blood flow patterns in imagery tasks -- results of single photon emission computer tomography. In M. Denis (Ed.), *Proceedings of the NATO Conference on Mental Imagery*.
- Golla, F. L., Hutton, E. L., & Gray Walter, W. G. (1943). The objective study of mental imagery. I. Physiological concomitants. *Journal of Mental Science*, 75, 216-223.
- Hebb D. O. (1968). Concerning imagery. *Psychological Review*, 75, 466-479.
- Heidenhain, A. (1927). Beitrag zur kenntnis der seelenblindheit. *Monatsschrift fur Psychiatrie und Neurologie*, 65, 61-116.
- Heilman, K. M., Watson, R. T., & Valenstein, E. (1985). Neglect and related disorders. In K. M. Heilman & E. Valenstein (Ed.), *Clinical Neuropsychology*. New York: 2nd edition.
- Hollins, M. (1985). Styles of mental imagery in blind adults. *Neuropsychologia*, 23, 561-566.
- Hume, D. (1969). *A Treatise in Human Nature*. Baltimore: Pelican Books. (1739)
- Ingvar, D. H., & Risberg, J. (1967). Increase of regional cerebral blood flow during mental

- effort in normals and in patients with local brain disorders. *Experimental Brain Research*, 3, 195-211.
- Intons-Peterson, M. J. (1983). Imagery paradigms: How vulnerable are they to experimenters' expectations? *Journal of Experimental Psychology: Human Perception and Performance*, 9, 394-412.
- Jossman, P. (1929). Zur psychopathologie des optisch-agnostischen storungen. *Monatsschrift fur Psychiatric und Neurologie*, 72, 81-149.
- Kerr, N. H. (1983). The role of vision in visual imagery experiments: Evidence from the congenitally blind. *Journal of Experimental Psychology: General*, 112, 265-277.
- Kosslyn, S.M. (1975). Information representation in visual images. *Cognitive Psychology*, 7, 341-370.
- Kosslyn, S.M. (1980). *Image and mind*. Cambridge: Harvard University Press.
- Kosslyn, S. M. (1983). *Ghosts in the Mind's Machine*. New York: Norton.
- Kosslyn, S. M., Ball, T. M., & Reiser, B. J. (1978). Visual images preserve metric spatial information: Evidence from studies of image scanning. *Journal of Experimental Psychology: Human Perception and Performance*, 4, 47-60.
- Lassen, N. A., Ingvar, D. H. and Skinhoj, E. (1978). Brain function and blood flow. *Scientific American*, 239, 62-71.
- Lesevre, N. & Joseph, J. P. (1980). Hypotheses concerning the most probable origins of the various components of the pattern evoked potential. In C. Barber (Ed.) *Evoked Potentials*. MTP Press.
- Lewandowsky, M. (1908). Ueber abspaltung des farbenses. *Monatsschrift fur Psychiatric and Neurologie*, 23, 488-510.
- Lezak, M. (1983) 2nd Ed. *Neuropsychological assessment*. New York: Oxford University Press.
- Lingoes, J.C. (1979) *The Guttman-Lingoes nonmetric program series*. Ann Arbor: Mathesis

Press.

- Maler, J., Dagnelie, G., Spekrijse, H., & VanDijk, B. W. (1987). Principle components analysis for source localization of visual evoked potentials in man. *Vision Research*, 12, 165-177.
- Marmor, G. S., & Zabeck, L. A. (1976). Mental rotation by the blind: Does mental rotation depend on visual imagery? *Journal of Experimental Psychology: Human Perception and Performance*, 2, 515-521.
- Mazziotta, J.C., Phelps, M.E., and Halgren, E. (1983). Local cerebral glucose metabolic response to audiovisual stimulation and deprivation: studies in human subjects with positron CT. *Human Neurobiology*, 2, 11-23.
- Meadows, J. C. (1974). The anatomical basis of prosopagnosia. *Journal of Neurology, Neurosurgery, and Psychiatry*, 37, 489-501.
- Neisser, U., & Kerr, N. (1973). Spatial and mnemonic properties of visual images. *Cognitive Psychology*, 5, 138-150.
- Nowlis, D. P., & Kamiya, J. (1970). The control of electroencephalographic alpha rhythms through auditory feedback and associated mental activity. *Journal of Neuroscience*, 6, 476-484.
- Perrin, F., Bertrand, O., & Pernier, J. (1986). Scalp current density mapping: Value estimation from potential data. *IEEE Biomedical Engineering*, 34, 283-288.
- Podgorny, P., & Shepard, R. N. (1978). Functional representations common to visual perception and imagination. *Journal of Experimental psychology: Human Perception and Performance*, 9, 21-35.
- Posner, M. I., Walker, J. A., Friedrich, F. J., & Rafal, R. D. (1984). Effects of parietal lobe injury on covert orienting of visual attention. *Journal of Neuroscience*, 4, 1863-1874.
- Pylyshyn, Z. W. (1973). What the mind's eye tells the mind's brain: A critique of mental

- imagery. *Psychological Bulletin*, 80, 1-24.
- Pylyshyn, Z. W. (1978). Imagery and artificial intelligence. In C. W. Savage (Ed.), *Perception and Cognition: Minnesota Studies in the Philosophy of Science*. Minneapolis, MN: University of Minnesota Press.
- Pylyshyn, Z. W. (1981). The imagery debate: Analogue media versus tacit knowledge. *Psychological Review*, 88, 16-45.
- Pylyshyn, Z. W. (1984). *Computation and cognition*. Cambridge, MA: MIT Press.
- Riddoch, M. J., and Humphreys, G. W. (). A case of integrative visual agnosia. *Brain*.
- Roland, P.E. (1982). Cortical regulation of selective attention in man. *Journal of Neurophysiology*, 48, 1059-1078.
- Roland, P. E., & Friberg, L. (1985). Localization of cortical areas activated by thinking. *Journal of Neurophysiology*, 53, 1219-1243.
- Roland, P.E., and Skinhoj, E. (1981). Focal activation of the cerebral cortex during visual discrimination in man. *Brain Research*, 222, 166-171.
- Shepard, R. N. (1978). The mental image. *American Psychologist*, 33, 125-137. (b)
- Shepard, R. N. (1984). Kinematics of perceiving, imagining, thinking, and dreaming. *Psychological Review*, 91(4), 417-447.
- Shepard, R. N., & Cooper, L. A. (1982). *Mental images and their transformations*. Cambridge, MA: MIT Press.
- Short, P. L. (1953). The objective study of mental imagery. *British Journal of Psychology*, 44, 38-51.
- Shuttleworth, E. C., Syring, V., and Allen, N. (1982). Further observations on the nature of prosopagnosia. *Brain and Cognition*, 1, 302-332.
- Slatter, K. H. (1960). Alpha rhythm and mental imagery. *Electroencephalography, and Clinical Neurophysiology*, 12, 851-859.
- Symonds, C., & Mackenzie, I. (1957). Bilateral loss of vision from cerebral infarction. *Brain*.

80, 28-448.

Ungerleider, L. G., & Mishkin, M. (1982). Two cortical visual systems. In D. J. Ingle,

M. A. Goodale, & M. J. W. Mansfield (Ed.), *Analysis of Visual Behavior*. Cambridge

MA: MIT Press.

Zimler, J., & Keenan, J. M. (1983). Imagery in the congenitally blind: How visual are visual

images? *Journal of Experimental Psychology: Learning, Memory, & Cognition*, 9, 269-282

Dr. Troy D. Abell
Oklahoma University
Health Sciences Center
800 N.E. 15th Street
Oklahoma City, OK 73190

Dr. Phillip L. Ackerman
University of Minnesota
Department of Psychology
Minneapolis, MN 55455

Dr. Beth Adelson
Department of Computer Science
Tufts University
Medford, MA 02155

AFOSR
Life Sciences Directorate
Phillip Air Force Base
Washington, DC 20332

Technical Director,
Army Human Engineering Lab
Aberdeen Proving Ground
MD 21005

Dr. Robert Ahlers
Code #711
Human Factors Laboratory
Naval Training Systems Center
Orlando, FL 32813

Dr. Ed Aiken
Navy Personnel R&D Center
San Diego, CA 92152-6800

Dr. Robert Allen
Temple University
School of Business Administration
Department of Computer and
Information Sciences
Philadelphia, PA 19122

Dr. John Allen
Department of Psychology
George Mason University
4400 University Drive
Fairfax, VA 22030

Dr. Earl A. Allulist
HQ, AFMRL (AFSC)
Brooks AFB, TX 78245

Dr. James Anderson
Brown University
Center for Neural Science
Providence, RI 02912

Dr. John R. Anderson
Department of Psychology
Carnegie-Mellon University
Pittsburgh, PA 15213

Dr. Nancy S. Anderson
Department of Psychology
University of Maryland
College Park, MD 20742

Technical Director, ARI
5001 Eisenhower Avenue
Alexandria, VA 22304

Dr. Gary Aston Jones
Department of Biology
New York University
1009 Main Bldg
Washington Square
New York, NY 10003

Dr. Lisa C. Baser
Oklahoma University
Health Sciences Center
800 N.E. 15th Street
Oklahoma City, OK 73190

Dr. Alvin Bitner
Naval Biodynamics Laboratory
New Orleans, LA 70189

Dr. Gordon H. Bower
Department of Psychology
Stanford University
Stanford, CA 94306

Dr. Robert Bowers
Code M 0958
Naval Training Systems Center
Orlando, FL 32814

Dr. John C. Brown
XEROX Palo Alto Research
Center
3333 Coyote Road
Palo Alto, CA 94304

Dr. Bruce Buchanan
Computer Science Department
Stanford University
Stanford, CA 94305

Mr. Niels Busch-Jensen
Forvarrets Center for Leadership
Christianhavns Voldgade 8
1424 København K
DENMARK

Joanne Capper
Center for Research into Practice
1718 Connecticut Ave., N.W.
Washington, DC 20009

Dr. J. J. Carbonell
Carnegie-Mellon University
Department of Psychology
Pittsburgh, PA 15213

Dr. Gail Carpenter
Northeastern University
Department of Mathematics, 300A
160 Huntington Avenue
Boston, MA 02115

Dr. Pat Carpenter
Carnegie-Mellon University
Department of Psychology
Pittsburgh, PA 15213

Dr. John M. Carroll
IBM Watson Research Center
User Interface Institute
P.O. Box 218
Yorktown Heights, NY 10598

Dr. Robert Carroll
Code 0187
Washington, DC 20310

Dr. Robert Carter
Office of the Chief
of Naval Operations
OP-018
Pentagon
Washington, DC 20350-2000

Dr. Fred Chang
Strategic Technology Division
Pacific Bell
2600 Camino Ramon
RM. 3S-453
San Ramon, CA 94583

Dr. Alphonse Chapanis
8415 Bellona Lane
Suite 210
Buxton Towers
Baltimore, MD 21204

Dr. Paul R. Chatelier
OHSU/IRI
Pentagon
Washington, DC 20330-2000

Mr. Raymond E. Christal
AFHRL/MSE
Brooks AFB, TX 78245

Professor Chu Tien-Chen
Mathematics Department
National Taiwan University
Taipei, TAIWAN

Dr. William Clancy
Stanford University
Knowledge Systems Laboratory
701 Welch Road, Bldg. 1
Palo Alto, CA 94304

Dr. David F. Clement
Department of Psychology
University of South Carolina
Columbia, SC 29208

Assistant Chief of Staff
for Research, Development,
Test, and Evaluation
Naval Education and
Training Command (NEDC)
NAEPensacola, FL 32508

Dr. Michael Cole
University of Illinois
Department of Psychology
Champaign, IL 61820

Dr. Allen M. Collins
Bolt Berne & Newman, Inc.
50 Moulton Street
Cambridge, MA 02138

Dr. Stanley Gollner
Office of Naval Technology
Code 222
800 M. Quincey Street
Arlington, VA 22217-5000

Dr. Leon Cooper
Brown University
Center for Neural Science
Providence, RI 02912

Dr. Lynn A. Cooper
Learning R&D Center
University of Pittsburgh
3939 O'Hara Street
Pittsburgh, PA 15213

Capt. Jorge Correia Jesuino
Marinha-7A Reparticao
Direccao Do Servico De Pessoal
Praça Do Comercio
Lisbon
PORTUGAL

M.C.S. Louis Crocq
Secrétariat Général de la
Défense Nationale
51 Boulevard de Latour-Maubourg
75007 Paris
FRANCE

Dr. Hans Gremberg
University of Leyden
Education Research Center
Bierhuysenvaai 2
2316 EB Leyden
The NETHERLANDS

CAPT P. Michael Curran
Office of Naval Research
800 M. Quincey St.
Code 125
Arlington, VA 22217-5000

Patricia Dallan
1400 THEATRICALS
Lowry AFB, CO 80130-5000

Dr. Joel Davis
Office of Naval Research
Code 114IMP
800 North Quincey Street
Arlington, VA 22217-5000

LT John Deaton
ONR Code 125
800 M. Quincey Street
Arlington, VA 22217-5000

Dr. R. K. Dismukes
Associate Director for Life Sciences
AFOSR
Boiling AFB
Washington, DC 20332

Dr. Stephanie Ivan
Code 6021
Naval Air Development Center
Warminster, PA 18974-5000

Dr. Emanuel Donchin
University of Illinois
Department of Psychology
Champaign, IL 61820
(Defense Technical
Information Center
Cameron Station, Bldg 5
Alexandria, VA 22304
Attn: DTIC
112 Copies)

Dr. Helmut Jürgen Ehrenfeld
Streitkräfteamt, Abteilung I
Bundesrat, Abteilung I
Postfach 20 00 00
11100 Bonn
FEDERAL REPUBLIC OF GERMANY

Dr. Ewald Fries
Brown University
Anatomy Department
Medical School
Providence, RI 02912

Dr. Jeffrey Kwan
University of California
San Diego
Department of Engineering Sciences
La Jolla, CA 92037

Dr. Richard Eyster
Deputy Assistant Secretary
of the Navy (Manpower)
ONAS (MANA)
Department of the Navy
Washington, DC 20340-1000

ERIC Facility Acquisitions
4833 Rugby Avenue
Bethesda, MD 20814

Dr. Jerome A. Feldman
University of Rochester
Computer Science Department
Rochester, NY 14627

Dr. Paul Fel'tovich
Southern Illinois University
School of Medicine
Medical Education Department
P.O. Box 1936
Springfield, IL 62708

Dr. Craig L. Fields
ARPA
1400 Wilson Blvd.
Arlington, VA 22209

Dr. Gail R. Flitschaker
Margulis Lab
Biological Sci. Center
2 Cunningham Street
Boston, MA 02215

J. D. Fletcher
9331 Corsica Street
Vienna VA 22180

Dr. Jane M. Flynn
Department of Psychology
George Mason University
Quant University Drive
Fairfax, VA 22030

Dr. Michael Friendly
Psychology Department
York University
Toronto, ONT
CANADA M3J 1E3

Dr. M. Fella Collagen
University of North Carolina
Department of Psychology
Chapel Hill, NC 27514

Dr. Don Gentner
Center for Human
Information Processing
University of California
La Jolla, CA 92093

Dr. Claude Ghez
Center for Neurobiology and
Behavior
772 W. 168th Street
New York, NY 10032

Dr. Lee Giles
AFOSR
Boiling AFB
Washington, DC 20332

Dr. Eugene F. Gloys
Office of Naval Research
(Settlement)
1040 F. Green Street
Pasadena, CA 91106-2486

Dr. Sam Gluckberg
Department of Psychology
Princeton University
Princeton, NJ 08540

Dr. Daniel Gopher
Industrial Engineering
& Management
TECHNION
Haifa 31000
ISRAEL

Dr. Sherrie Gott
Allied Model
Boiling AFB, TX 78107

Jordan Grisman, Ph.D.
2001 Lyttonville Road
Silver Spring, MD 20910

Dr. Richard H. Granger
Department of Computer Science
University of California, Irvine
Irvine, CA 92717

Dr. Steven Grant
Department of Biology
New York University
1009 Main Bldg
Washington Square
New York, NY 10003

Dr. Wayne Gray
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. William Greenough
University of Illinois
Department of Psychology
Champaign, IL 61820

Dr. Stephen Grossberg
Center for Adaptive Systems
Room 244
111 Cunningham Street
Boston University
Boston, MA 02215

Dr. Muhammad K. Habib
University of North Carolina
Department of Biostatistics
Chapel Hill, NC 27514

Dr. Henry M. Halfr
Halfr Resources, Inc.
4918 33rd Road, North
Arlington, VA 22207

Dr. Ronald K. Hambleton
Prof. of Education & Psychology
University of Massachusetts
at Amherst
Hills House
Amherst, MA 01003

Dr. Ray Hannapel
Scientific and Engineering
Personnel and Education
National Science Foundation
Washington, DC 20550

Steven Harned
Editor, The Behavioral and
Brain Sciences
20 Nassau Street, Suite 240
Princeton, NJ 08540

Dr. Steven A. Hillyard
Department of Neurosciences
University of California,
San Diego
La Jolla, CA 92093

Dr. Geoffrey Hinton
Carnegie-Mellon University
Computer Science Department
Pittsburgh, PA 15213

Dr. Jim Hollan
Intelligent Systems Group
Institute for
Cognitive Science (C-015)
UCSD
La Jolla, CA 92093

Dr. John Holland
University of Michigan
2113 East Engineering
Ann Arbor, MI 48109

Dr. Keith Holyoak
University of Michigan
Human Performance Center
310 Packard Road
Ann Arbor, MI 48109

Dr. James Howard
Dept. of Psychology
Human Performance Laboratory
Catholic University of
America
Washington, DC 20064

Dr. Earl Hunt
Department of Psychology
University of Washington
Seattle, WA 98105

Dr. Ed Hutchins
Intelligent Systems Group
Institute for
Cognitive Science (C-015)
UCSD
La Jolla, CA 92093

Dr. Alice Isen
Department of Psychology
University of Maryland
Catonaville, MD 21718

Pharm.-Chim. en Chef Jean Laig
Division de Psychologie
Centre de Recherches du
Service de Sante des Armees
108 Boulevard Pinel
69272 Lyon Cedex 03, FRANCE

COL Dennis M. Jarvi
Commander
AFMRL
Brooks AFB, TX 78235-5601

CDR Tom Jones
125
OMR Code 125
800 M. Quincy Street
Arlington, VA 22217-5000

Dr. Douglas H. Jones
Thatcher Jones Associates
P.O. Box 6640
10 Trafalgar Court
Lawrenceville, NJ 08648

Col. Dominique Jouslin de Moray
Etat-Major de l'Armee de Terre
Centre de Relations Humaines
3 Avenue Octave Greard
75007 Paris
FRANCE

Dr. Marcel Just
Carnegie-Mellon University
Department of Psychology
Schenley Park
Pittsburgh, PA 15213

Dr. Daniel Kahneman
Department of Psychology
University of California
Berkeley, CA 94720

Dr. Demetrios Karis
Gumman Aerospace Corporation
MS C04-14
Bethpage, NY 11714

Dr. Milton S. Katz
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. Steven M. Keele
Department of Psychology
Cornell University
Ithaca, NY 14850

Dr. Frank Kell
Department of Psychology
Cornell University
Ithaca, NY 14850

Dr. Scott Kelso
Haskins Laboratories,
270 Green Street
New Haven, CT 06510

Dr. Dennis Kibler
University of California
Department of Information
and Computer Science
Irvine, CA 92717

Dr. Ronald Knoll
Bell Laboratories
Murray Hill, NJ 07974

Dr. Sylvan Kornblum
University of Michigan
Mental Health Research Institute
205 Washtenaw Place
Ann Arbor, MI 48109

Dr. Stephen Kosslyn
Harvard University
1216 William James Hall
33 Kirkland St.
Cambridge, MA 02138

Dr. Benjamin Kuipers
University of Texas at Austin
Department of Computer Sciences
T.S. Painter Hall 4.28
Austin, Texas 78712

Dr. Pat Langley
University of California
Department of Information
and Computer Science
Irvine, CA 92717

| | | |
|---|--|---|
| Dr. Mercy Lannan University of North Carolina The L. L. Thurstone Lab. Davis Hall 0134 Chapel Hill, NC 27514 | Dr. William L. Maloy Chief of Naval Education and Training Naval Air Station Pensacola, FL 32508 | Dr. Harold F. O'Neill, Jr. School of Education - MH 801 Department of Educational Psychology & Technology University of Southern California Los Angeles, CA 90089-0031 |
| Dr. Robert Lawler Information Sciences, FRL GTE Laboratories, Inc. 40 Sylvan Road Waltham, MA 02254 | Dr. Evans Mandes Department of Psychology George Mason University 4400 University Drive Fairfax, VA 22030 | Dr. Michael Meriln Naval Training Systems Center Code 111 Orlando, FL 32814-7100 |
| Dr. Alan M. Lesgold Learning R&D Center Pittsburgh, PA 15260 | Dr. Jay McClelland Department of Psychology Carnegie-Mellon University Pittsburgh, PA 15213 | Dr. Stellan Ohlsson Learning R & D Center University of Pittsburgh 1039 O'Hara Street Pittsburgh, PA 15213 |
| Dr. Charles Lewis Faculteit Sociale Wetenschappen Rijksuniversiteit Groningen Oude Boteringestraat 23 9712GC Groningen The NETHERLANDS | Dr. James L. McCaughy Center for the Neurobiology of Learning and Memory University of California, Irvine Irvine, CA 92717 | Dr. James R. Olson Director, Waterford Testing Center 1681 West 870 North Provo, UT 84601 |
| Library Naval War College Newport, RI 02940 | Dr. Call McKoon CAS/Psychology Northwestern University 1859 Sheridan Road Evanston, IL 60201 | Director, Research Programs, Office of Naval Research 800 North Quincy Street Arlington, VA 22217-5000 |
| Library Naval Training Systems Center Orlando, FL 32813 | Dr. Joe McLachlan Navy Personnel R&D Center San Diego, CA 92152-6800 | Office of Naval Research, Code 1133 800 M. Quincey Street Arlington, VA 22217-5000 |
| Science and Technology Division Library of Congress Washington, DC 20540 | Dr. James McMichael Assistant for MIT Research, Development, and Studies OP 0187 Washington, DC 20370 | Office of Naval Research, Code 1141MP 800 M. Quincey Street Arlington, VA 22217-5000 |
| Dr. Bob Lloyd Dept. of Geography University of South Carolina Columbia, SC 29208 | Dr. George A. Miller Department of Psychology Green Hall Princeton University Princeton, NJ 08540 | Office of Naval Research, Code 1142 800 M. Quincey St. Arlington, VA 22217-5000 |
| Dr. Gary Lynch University of California Center for the Neurobiology of Learning and Memory Irvine, CA 92717 | Dr. William Montague NPRDC Code 11 San Diego, CA 92152-6800 | Office of Naval Research, Code 1142FF 800 M. Quincey Street Arlington, VA 22217-5000 |
| Dr. Don Lyon P. O. Box 44 Higley, AZ 85236 | Commanding Officer, Naval Research Laboratory Code 2627 Washington, DC 20390 | |
| | Dr. Randy Munn Program Manager Training Research Division HumbRO 1100 S. Washington Alexandria, VA 22314 | |
| | Spec. Asst. for Research, Exper- imental & Academic Programs, MTTC (Code 016) NAS Memphis (75) Hillington, TN 38054 | |
| | Leadership Management Education and Training Project Officer, Naval Medical Command Code 05C Washington, DC 20372 | |
| | Dr. Mary Jo Mussen University of Minnesota 2218 Elliott Hall Minneapolis, MN 55455 | |
| | Director, Training Laboratory, NPRDC (Code 05) San Diego, CA 92152-6800 | |
| | Director, Manpower and Personnel Laboratory, NPRDC (Code 06) San Diego, CA 92152-6800 | |
| | Director, Human Factors & Organizational Systems Lab, NPRDC (Code 07) San Diego, CA 92152-6800 | |
| | Fleet Support Office, NPRDC (Code 301) San Diego, CA 92152-6800 | |
| | Library, NPRDC Code P201L San Diego, CA 92152-6800 | |

- Dr. Steven Grant
Department of Biology
New York University
1009 Main Bldg
Washington Square
New York, NY 10003
- Dr. Wayne Gray
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333
- Dr. William Greenough
University of Illinois
Department of Psychology
Champaign, IL 61820
- Dr. Stephen Grossberg
Center for Adaptive Systems
Room 248
111 Cunningham Street
Boston University
Boston, MA 02215
- Dr. Muhammad K. Habib
University of North Carolina
Department of Biostatistics
Chapel Hill, NC 27514
- Dr. Henry M. Haliff
Haliff Resources, Inc.
4918 33rd N.W., North
Arlington, VA 22207
- Dr. Ronald K. Hambleton
Prof. of Education & Psychology
University of Massachusetts
at Amherst
Hills House
Amherst, MA 01003
- Dr. Ray Hannapel
Scientific and Engineering
Personnel and Education
National Science Foundation
Washington, DC 20550
- Steven Harnad
Editor, The Behavioral and
Brain Sciences
20 Massau Street, Suite 240
Princeton, NJ 08540
- Dr. Steven A. Hillyard
Department of Neurosciences
University of California,
San Diego
La Jolla, CA 92093
- Dr. Geoffrey Hinton
Carnegie-Mellon University
Computer Science Department
Pittsburgh, PA 15213
- Dr. Jim Hollan
Intelligent Systems Group
Institute for
Cognitive Science (C-015)
UCSD
La Jolla, CA 92093
- Dr. John Holland
University of Michigan
2113 East Engineering
Ann Arbor, MI 48109
- Dr. Keith Holyoak
University of Michigan
Human Performance Center
340 Packard Road
Ann Arbor, MI 48109
- Dr. James Howard
Dept. of Psychology
Human Performance Laboratory
Catholic University of
America
Washington, DC 20064
- Dr. Earl Hunt
Department of Psychology
University of Washington
Seattle, WA 98195
- Dr. Ed Hutchins
Intelligent Systems Group
Institute for
Cognitive Science (C-015)
UCSD
La Jolla, CA 92093
- Dr. Alice Isen
Department of Psychology
University of Maryland
Catonaville, MD 21228
- Pharm.-Chim. en Chef Jean Jaq
Division de Psychologie
Centre de Recherches du
Service de Sante des Armees
108 Boulevard Pine
69272 Lyon Cedex 03, FRANCE
- COL Dennis W. Jarvis
Commander
AFMRL
Brooks AFB, TX 78235-5601
- CDR Tom Jones
OMR Code 125
800 W. Quincy Street
Arlington, VA 22217-5000
- Dr. Douglas H. Jones
Thatcher Jones Associates
P.O. Box 6640
10 Trafalgar Court
Lawrenceville, NJ 08648
- Col. Dominique Jouslin de Moray
Etat-Major de l'Armee de Terre
Centre de Relations Humaines
3 Avenue Octave Greard
75007 Paris
FRANCE
- Dr. Marcel Just
Carnegie-Mellon University
Department of Psychology
Schenley Park
Pittsburgh, PA 15213
- Dr. Daniel Kahneman
Department of Psychology
University of California
Berkeley, CA 94720
- Dr. Demetrios Karis
Grumman Aerospace Corporation
MS C04-14
Bethpage, NY 11714
- Dr. Milton S. Katz
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333
- Dr. Steven M. Kiehl
Department of Psychology
University of Oregon
Eugene, OR 97403
- Dr. Frank Kell
Department of Psychology
Cornell University
Ithaca, NY 14850
- Dr. Scott Kelso
Haskins Laboratories,
270 Crown Street
New Haven, CT 06510
- Dr. Dennis Kibler
University of California
Department of Information
and Computer Science
Irvine, CA 92717
- Dr. Ronald Knoll
Bell Laboratories
Murray Hill, NJ 07974
- Dr. Sylvan Kounin
University of Michigan
Mental Health Research Institute
205 Washenaw Place
Ann Arbor, MI 48109
- Dr. Stephen Kosslyn
Harvard University
1236 William James Hall
33 Kirkland St.
Cambridge, MA 02138
- Dr. Benjamin Kuipers
University of Texas at Austin
Department of Computer Sciences
T.S. Painter Hall 3.1.8
Austin, Texas 78712
- Dr. Pat Langley
University of California
Department of Information
and Computer Science
Irvine, CA 92717

Office of Naval Research,
Code 11429F
800 M. Quincy Street
Arlington, VA 22217-5000
(6 Copies)

Director, Technology Programs,
Office of Naval Research
Code 12
800 North Quincy Street
Arlington, VA 22217-5000

Psychologist
Office of Naval Research
Branch Office, London
Box 39
FPO New York, NY 09510

Special Assistant for Marine
Corps Matters,
OMR Code 00MC
800 M. Quincy St.
Arlington, VA 22217-5000

Psychologist
Office of Naval Research
Liaison Office, Far East
APO San Francisco, CA 96503

Assistant for Planning MAINTRAPERS
OP 01B6
Washington, DC 20370

Assistant for MPT Research,
Development and Studies
OP 01B7
Washington, DC 20370

Assistant for Personnel
Logistics Planning,
OP 987H
50772, The Pentagon
Washington, DC 20350

Dr. Judith Grasen
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. Robert F. Pasnak
Department of Psychology
George Mason University
4400 University Drive
Fairfax, VA 22030

Daire Paulson
Code 52 - Training Systems
Navy Personnel R&D Center
San Diego, CA 92152-0600

Dr. Douglas Pearce
DCIDN
Box 2000
Downsview, Ontario
CANADA

Dr. James W. Pellegrino
University of California,
Santa Barbara
Department of Psychology
Santa Barbara, CA 93106

Military Assistant for Training and
Personnel Technology,
ONSD (R & F)
Room 3D129, The Pentagon
Washington, DC 20301-3080

Dr. Ray Perez
ARI (PERI-11)
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. Steven Pinker
Department of Psychology,
F10-01B
M.I.T.
Cambridge, MA 02139

Dr. Martha Polson
Department of Psychology
Campus Box 146
University of Colorado
Boulder, CO 80309

Dr. Peter Polson
University of Colorado
Department of Psychology
Boulder, CO 80309

Dr. Michael J. Posner
Department of Neurology
Washington University
Medical School
St. Louis, MO 63110

Dr. Mary C. Potter
Department of Psychology
MIT (E-10-032)
Cambridge, MA 02139

Dr. Karl Pribram
Stanford University
Department of Psychology
Bldg. 4201 -- Jordan Hall
Stanford, CA 94305

Lt. Jose Puente Ontanilla
C/Santísima Trinidad, 8, 4 F
28010 Madrid
SPAIN

Dr. James A. Reggia
University of Maryland
School of Medicine
Department of Neurology
22 South Greene Street
Baltimore, MD 21201

Dr. Gil Ricard
Mail Stop C08-14
Grumman Aerospace Corp.
Bethpage, NY 11714

Ms. Riitta Ruotsalainen
General Headquarters
Training Section
Military Psychology Office
PL 919
SF-00101 Helsinki 10, FINLAND

Dr. F. L. Saltzman
Haskins Laboratories
270 Crown Street
New Haven, CT 06510

Dr. Arthur Samuel
Yale University
Department of Psychology
Box 11A, Yale Station
New Haven, CT 06520

Ms. Ringvold, Thuelellbach
Forwards Center for Lederstab
Christianshavns Voldgade 8
1424 København K
DENMARK

Dr. Walter Schneider
Learning R&D Center
University of Pittsburgh
3939 O'Hara Street
Pittsburgh, PA 15260

Dr. Robert J. Seidel
US Army Research Institute
5001 Eisenhower Ave.
Alexandria, VA 22333

Dr. Colleen M. Selfert
Intelligent Systems Group
Institute for
Cognitive Science (C-015)
UCSD
La Jolla, CA 92093

Dr. T. R. Sheridan
Dept. of Mechanical Engineering
MIT
Cambridge, MA 02139

Dr. Zita M. Simutis
Instructional Technology
Systems Area
ARI
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. H. Wallace Sinalko
Mangover Research
and Advisory Services
Smithsonian Institution
801 North Pitt Street
Alexandria, VA 22304

LIC Juhani Sinivuori
General Headquarters
Training Section
Military Psychology Office
PL 919
SF-00101 Helsinki 10, FINLAND

Dr. Edward E. Smith
Bolt Beranek & Newman, Inc.
50 Moulton Street
Cambridge, MA 02138

Dr. Linda B. Smith
Department of Psychology
Indiana University
Bloomington, IN 47405

Dr. Robert F. Smith
Department of Psychology
George Mason University
4400 University Drive
Fairfax, VA 22030

Dr. Richard E. Snow
Department of Psychology
Stanford University
Stanford, CA 94306

Dr. Kathryn T. Spoehr
Brown University
Department of Psychology
Providence, RI 02912

Dr. Ted Steinke
Dept. of Geography
University of South Carolina
Columbia, SC 29208

Dr. Saul Sternberg
University of Pennsylvania
Department of Psychology
3815 Walnut Street
Philadelphia, PA 19104

Medecin Philippe Stivalet
Division de Psychologie
Centre de Recherches du
Service de Sante des Armees
108 Boulevard Poincaré
69272 Lyon Cedex 03, FRANCE

Dr. Steve Suomi
MIM Bldg. 31
Room B2B-15
Bethesda, MD 20205

Dr. John Tangney
AFOSR/ML
Boiling AFB, DC 20332

Dr. Richard F. Thompson
Stanford University
Department of Psychology
Bldg. 4201 -- Jordan Hall
Stanford, CA 94305

Dr. Sharon Thacz
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. Michael T. Turvey
Haskins Laboratories
270 Crown Street
New Haven, CT 06510

Dr. James Tweeddale
Technical Director
Navy Personnel R&D Center
San Diego, CA 92152-6800

Dr. V. R. R. Uppluri
Union Carbide Corporation
Nuclear Division
P. O. Box Y
Oak Ridge, TN 37830

Headquarters, U. S. Marine Corps
Code MFI-20
Washington, DC 20380

Dr. William Uttal
MUSC, Hawaii Lab
Box 997
Kailua, HI 96734

Dr. J. M. M. Van Breukelen
Afd. Sociale Wetenschappelijke
Onderzoek/DRKM
Admiraliteitsgebouw
Van Der Burchlaan 11 Kr. 376
2500 ES 's-Gravenhage, NETHERLANDS

Dr. Kurt Van Iehm
Department of Psychology
Carnegie-Mellon University
Schenley Park
Pittsburgh, PA 15213

Dr. Jerry Vugt
Navy Personnel R&D Center
Code 51
San Diego, CA 92152-6800

Dr. H. J. M. Wassenberg
Head, Dept. of Behavioral Sciences
Royal Netherlands Air Force
Afd. Gedragwetenschappen/DPKLV
Blinckhorstlaan 135 Kr. 2, 4
2516 BA 's-Gravenhage, NETHERLANDS

Dr. Norman M. Weinberger
University of California
Center for the Neurobiology
of Learning and Memory
Irvine, CA 92717

Dr. Shih-Sung Wen
Jackson State University
1325 J. R. Lynch Street
Jackson, MS 39217

Dr. Douglas Wetzel
Code 12
Navy Personnel R&D Center
San Diego, CA 92152-6800

Dr. Barry Whitsel
University of North Carolina
Department of Physiology
Medical School
Chapel Hill, NC 27514

Dr. Christopher Wickens
Department of Psychology
University of Illinois
Champaign, IL 61820

Dr. Heather Wild
Naval Air Development
Center
Code 6021
Warminster, PA 18974-5000

Dr. Robert A. Wisher
U.S. Army Institute for the
Behavioral and Social Sciences
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. Martin F. Wiskoff
Navy Personnel R & D Center
San Diego, CA 92152-6800

Dr. Dan Wolz
AFHRL/MOE
Brooks AFB, TX 78245

Dr. George Wong
Biostatistics Laboratory
Memorial Sloan-Kettering
Cancer Center
1275 York Avenue
New York, NY 10021

Dr. Donald Woodward
Office of Naval Research
Code 114MP
800 North Quincy Street
Arlington, VA 22217-5000

Dr. Wallace Mulleck, III
Navy Personnel R&D Center
San Diego, CA 92152-6800

Dr. Joe Yasutake
AFHRL/LRT
Lowry AFB, CO 80240

Dr. Masoud Yazdani
Dept. of Computer Science
University of Exeter
Exeter EX4 4QL
Devon, ENGLAND

Mr. Carl York
System Development Foundation
181 Lytton Avenue
Suite 210
Palo Alto, CA 94301

Dr. Joseph L. Young
Memory & Cognitive
Processes
National Science Foundation
Washington, DC 20550

Dr. Steven Zornetzer
Office of Naval Research
Code 1140
800 N. Quincy St.
Arlington, VA 22217-5000

Dr. Michael J. Zyda
Naval Postgraduate School
Code 52CK
Monterey, CA 93943-5100

END

9-87

DTIC